MO'Power to the Customer: An Evaluation of a Dual Fuel Home Energy Reports Program

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ABSTRACT

Energy savings programs featuring behavioral elements are in vogue. Home energy reports represent a relatively pure form of behavioral based energy conservation program -- there is no use of pricing and there is no technology providing automated control or real-time displays. Participating households receive mailings which provide energy comparisons to their neighbors, personal comparisons to their own energy consumption, and targeted energy saving tips.

This paper evaluates 20 months of savings results from a Home Energy Reports Program sponsored by Puget Sound Energy. Starting in November 2008, roughly 40,000 households in the utility's territory began receiving the reports from Opower. This program was the second program implemented by Opower and it was the first to be offered to households that used both natural gas and electricity. The program was designed as a randomized controlled trial.

The impact evaluation of the program used actual month billing data produced using daily AMI data. The paper examines annual and monthly electric and natural gas savings within the first 20 months. The analysis also teases out the effects of quarterly reports compared with the typical monthly schedule. Finally, the paper provides the results of an attribution analysis to determine whether energy savings came from behavior change or from the installation of other utility-sponsored (and rebated) energy efficiency programs.

Introduction

In an effort to better understand the energy savings potential of residential behavior-based conservation programs, Puget Sound Energy (PSE) launched a pilot program with OPOWER to measure the impacts of Home Energy Reports (HER) on energy consumption for single family, dual fuel households. Launched in November 2008, the program provides a monthly or quarterly Home Energy Report to nearly 40,000 households in PSE's combined gas and electric service territory.

In 2010, PSE hired KEMA to estimate the impact of the HER on the energy consumption of recipients. KEMA estimated savings by conduct a billing analysis of the randomly assigned recipient and control groups of customers who were selected from a pool of potential participants of the HER Program. The analysis developed annual and monthly electric and natural gas savings within the first 20 months. The analysis also compared the effects of quarterly reports with the typical monthly schedule of mailings. Finally, the analysis included an attribution analysis to determine whether energy savings came from behavior change or from the installation of other utility-sponsored (and rebated) energy efficiency programs.

Program Background

The HER program provides a monthly or quarterly HER to nearly 40,000 households in PSE's combined gas and electric service territory. The reports are designed to provide recipients with feedback on their household energy use, how their usage compares with that of neighboring homes, and custom tips on how a household can reduce their energy consumption. PSE's program is designed with two delivery mechanisms: a monthly report and a quarterly report. Participating households are assigned to either the monthly group or the quarterly group; never to both groups. Each month, three quarters of the households in the treatment group receive a HER which provides details on their household energy usage and tips on using energy wisely. Once every quarter, the remaining households in the treatment group receive a report with the same information provided to the monthly recipients.

Experimental Design Background

HER Programs have both the opportunity and necessity of working within an experimental design framework. In this respect HER Programs stand in contrast to most other energy efficiency programs. HER programs require a particularly robust, unbiased evaluation result given the relatively small magnitude of expected savings in percentage terms. In turn, the HER program offering is amenable to implementation in an experimental design framework unlike most other kinds of programs.

Before the PSE HER program launched, a group of 83,811 single family homes, located in PSE's combined gas and electric service territory, were selected to participate in the experiment, either as a recipient or control group participant. Households were selected to participate on the experiment based on the following criteria: dual fuel (using both natural gas and electricity provided by PSE), single family residential home, uses more than 80 MBtu of energy per year, home does not utilize a Solar PV system, home address must be available with parcel data from the county assessor, home has as a bill history that starts on or before January 1, 2007, home must have 100 similar sized homes (neighbors) within a two mile radius, and the home must have automatic daily meter reads.

After selection of the experiment households was complete, 39,755 homes were randomly assigned to participate in the recipient group and the remaining homes serve as a control group. Of the selected recipient homes, 9,949 (25%) were randomly selected to receive reports on a quarterly basis, while the remaining 29,806 (75%) homes are participating as monthly report recipients. The random assignment of monthly and quarterly reports allows both PSE and OPOWER to test the effect of report frequency on energy savings.

Methodological Approach

The evaluation of PSE's HER program used two analysis approaches. The first approach was a basic difference-of-differences approach. The difference-of-differences approach leverages the experimental design of the HER program to produce a simple, intuitive estimate of program impacts.

For the second analysis approach, KEMA used a pooled, fixed effects model. The pooled model explicitly accounts for both individual household baseload and systematic time period effects. By controlling for individual effects, monthly effects and weather, the pooled approach reduces the standard error of the impact estimate. Of equal importance, the model makes it possible to normalize the estimates of program savings to reflect typical weather conditions. The final aggregate impact estimates are produced with this model.

Difference-of-Differences

The difference-of-differences approach is the most direct and simple way of leveraging the experimental design of the HER program. The approach compares the difference in treatment group average consumption between pre- and post-report period with the same difference for the control group. The treatment group pre-post difference captures all changes between the two periods including those related to receiving the reports. The control group captures all changes with the exception of those related to the report. The random selection of the treatment and control groups ensures that, on average, the control group will appropriately reflect the non-report related changes experienced by treatment and control group alike between the pre-and post-report periods. Removing the non-report differences from the treatment difference, as represented by the control group difference, produces an unbiased estimate of the report's isolated effect on consumption.

According to the experimental design, pre-report differences should be non-existent while post-report differences reflect the effect of the reports. Either kind of observed difference between participants and non-participants is unlikely to be evenly distributed across the year. In a difference of differences framework, it is ideal if pre- and post-report periods cover the same 12 month increments for both participants and non-participants. In this case, the pre-period "adjustment" due to random differences in the groups prior to mailing of reports reflects the difference between the two groups across a full year. Similarly, the post period, 12-month increments will represent annual estimates of savings.

Importantly, despite the presence of the control group, difference-of-differences impact estimates reflect the observed weather during the analysis period. The standard practice of reporting program savings on a typical year basis is not possible with the differences of differences approach.

The average consumption of energy for the treatment group in the pre-report period is calculated with the equation:

$$\overline{E}_{Trmt\,\mathrm{Pre}} = \frac{1}{n_{Trmt}} \sum_{i \in Trmt} E_i$$

$\overline{E}_{Trmt\,\mathrm{Pre}}$	=	Average, 12 month energy consumption in the pre-report period for the treatment group;
n_{Trmt}	=	Count of households in the treatment group;
E_i	=	12 month energy consumption for household i;

Using this equation structure, average energy consumption is calculated for both treatment and control groups in both the pre- and post-report periods. The difference of differences is then produced with the following equation.

$$\Delta E = \left(\overline{E}_{Trmt\,\mathrm{Pre}} - \overline{E}_{TrmtPost}\right) - \left(\overline{E}_{Cont\,\mathrm{Pre}} - \overline{E}_{ContPpost}\right)$$

The difference-of-differences approach can be applied on a monthly or seasonal basis. As long as time periods are balanced in the pre- and post-report periods the savings estimate will be consistent for that time period.

Pooled Model

The primary impact estimates for this evaluation were based on a pooled regression approach to modeling the monthly consumption data. We estimated multiple specifications within a fixed effects framework. The basic fixed effects regression approach models all household monthly consumption as a combination of a household-specific baseload, average heating and cooling trends and monthly time-series effect. The model specification is structured to effectively replicate, in the regression framework, the difference-of-differences approach discussed above. The relevant output of the model is the modeled pre-post difference in the treatment group, net of the pre-post difference of the control group.

The pooled, fixed effects approach improves on the difference-of-differences approach by allowing final savings estimates that are derived with normalized weather. This means savings estimates represent expected savings in a typical weather year. The pooled approach also controls for between household variability reducing the standard errors on the impact estimates. Finally, the pooled approach can be run so as to produce heteroscedasticity-robust estimates of savings standard error. The pooled model approach produces results with precision better than ten percent at a 95 percent confidence level.

Basic Pooled Specification

The primary impact estimates for this evaluation are based on a pooled approach to modeling the monthly consumption data. We estimated multiple specifications within a fixed effects framework. The basic fixed effect specification has the following equation:

$$
\begin{aligned}
E_{it} = \mu_i + \lambda_t \quad & + \beta_2 T_i + \beta_3 P_t + \beta_4 T_i P_t \\
& + \beta_{H1} H_{it} + \beta_{H2} H_{it} T_i + \beta_{H3} H_{it} P_t + \beta_{H4} H_{it} T_i P_t \\
& + \beta_{C1} C_{it} + \beta_{C2} C_{it} T_i + \beta_{C3} C_{it} P_t + \beta_{C4} C_{it} T_i P_t \\
& + \varepsilon_{it}
\end{aligned}
$$

Where

E_{it}	=	Energy consumption per day during month *t* for customer *i*;
H_{it} *or* C_{it}	=	Average heating or cooling degree-days at the base temperature τ_H or τ_C during month *t*, based on daily average temperatures, for customer i's meter reading period;
T_i	=	One for households in the treatment group, 0 Otherwise;
P_t	=	One for time periods in the post-report period, 0 Otherwise;
μ_i	=	Household-specific base consumption estimate for customer i;
λ_t	=	Month-specific time period effect for month *t*;
β	=	Coefficients, determined by the regression;
ε_{it}	=	Regression residual.

The household fixed effect, μ_i in this model, captures the unique household level baseload consumption. The time period fixed effect, λ_t in this model, captures systematic monthly effects shared by all households. These fixed effects control for correlation of residual errors over time for an individual customer, and across customers for a given time period.

The experimental design is a simple 2x2 design: treatment and control by pre- and post-report. In the regression framework, the 2x2 design is represented by a base level (intercept), a treatment effect, a post-report effect and a combined treatment and post-report effect. Estimated together,

- the intercept represents average control group consumption in the pre-report period,
- the treatment effect captures the difference between treatment and control across all time periods,
- the post-report effect captures the difference between pre-and post-report periods for both treatment and control groups, and
- The combined treatment and post-report effect captures the marginal effect in the post-report period for the treatment group alone.

This basic structure applies to all weather and characteristic effects included in the model. In the pooled model specification provided above, the treatment effect, the post-report effect and the combined treatment and post-report effect are clearly evident in the base, heating and cooling portions of the model (T_i, P_t, and T_iP_t, respectively).

All four combinations are evident in the interactions with heating and cooling degree days. For the non-weather effects, the base level is represented by the household effect μ_i which is a unique intercept for each household.

Including degree-day terms is important to control for weather effects over time, and to make tracking of treatment effects over time more meaningful. Though the presence of the control group controls for weather effects between the pre- and post-report period, the estimated savings from the post-report period is still a function of the weather during the evaluation period. As with any energy efficiency impact estimate, the savings should be put on a typical year basis, so that savings do not reflect consumptions pattern from an evaluation timeframe defined by atypical weather.

Model Choice

A variety of model specifications have been discussed in the HER program evaluation literature. Within the pooled, fixed effect model framework[1], this model specification includes the best aspects of those models. Other research has proposed specifications with logged dependent variables with and without fixed effects and/or weather variables. At this point, the pooled, fixed effects approach pursued here reflects the best of the approaches coming out of the energy evaluation context.

Absorbed Pooled Specification

For an analysis with a sample the size of the PSE HER program, a fixed effect model strains the limits of most statistical computer programs. The household fixed effect enters the model as a matrix of dummy variables with dimensions equal to the number of customer in both the treatment and control groups. The inversion of a matrix of this magnitude is computationally challenging. Fortunately, for the linear fixed effects model, there is a way to transform the data that removes the matrix of dummy variables from the computation. Simply put, the same model is run with all variables de-meaned -- that is, all variables are replaced by their difference from the household level mean of that variable. The details of this approach are not discussed further here but are a key practical consideration for the development of these models.

[1] This would include Summit Blue's 2009 Impact Evaluation of OPOWER SMUD Pilot Study with their "best" model, the differenced linear effects model.

Model Results

Savings are estimated by fitting the absorbed pooled model parameters associated with the combined treatment (T_i) and the post (P_t) effects. For estimates of normalized savings, the degree days should be fit to degree days calculated using normal temperatures and the optimal degree day based determined for the model:

$$\Delta E = 365\,\hat{\beta}_4 + \hat{\beta}_{H4}\breve{H} + \hat{\beta}_{C4}\breve{C}$$

Where:

ΔE	=	Estimated annual energy savings;
$\breve{H}$	=	Normal annual heating degree-days at the optimal heating base temperature;
$\breve{C}$	=	Normal annual cooling degree-days at the optimal cooling base temperature;
$\hat{\beta}_4, \hat{\beta}_{H4}, \hat{\beta}_{C4}$	=	Estimated parameters from the absorbed, pooled model;

Program Results

Monthly Differences

Figures 1 and 2 provide the monthly treatment minus control group consumption differences for 39 months including 15 months in the pre- mailing period and 24 months in the post period. In the pre-mailing period for both fuels (to the left of the vertical line in both figures), the results are all or mostly below zero indicating slightly lower levels of consumption among treatment participants even prior to the mailings. These month differences are not statistically different than zero and would also be removed in the difference of difference framework. The post period shows consistent statistically significant reductions in consumption through the full two year post period. These results are presented as a visual reference of the program results[2].

[2] Difference of difference results were calculated separately for the full two-year post period after the submission of the report on which this paper is based. The remaining results reflect the 20 month post period addressed in the original report.

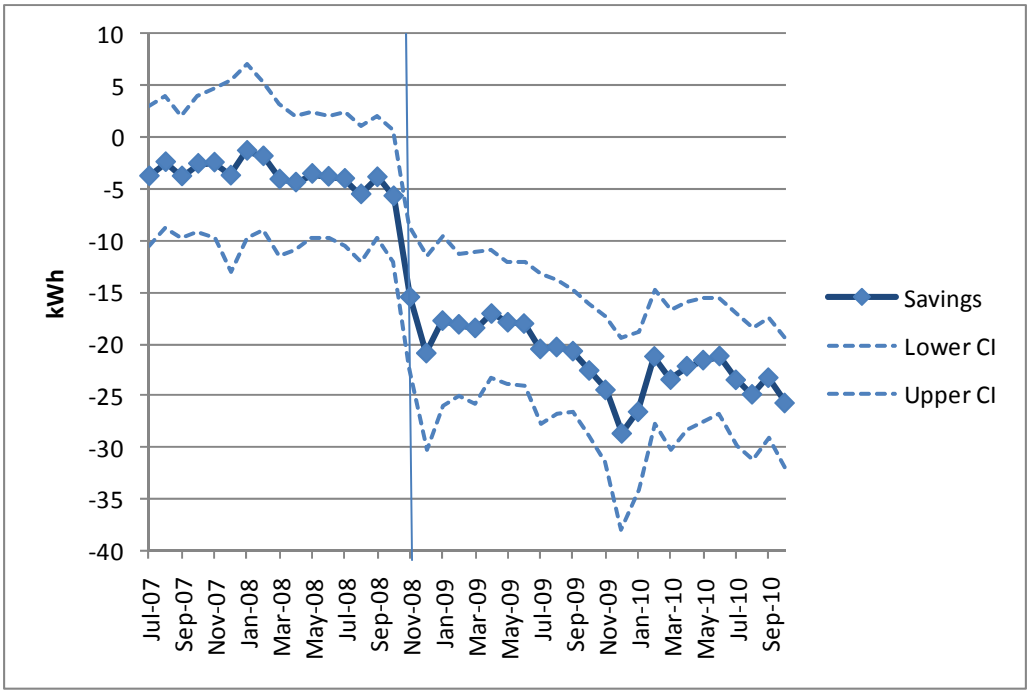

Figure 1. Average Household Monthly Electric Differences, Control vs Treatment

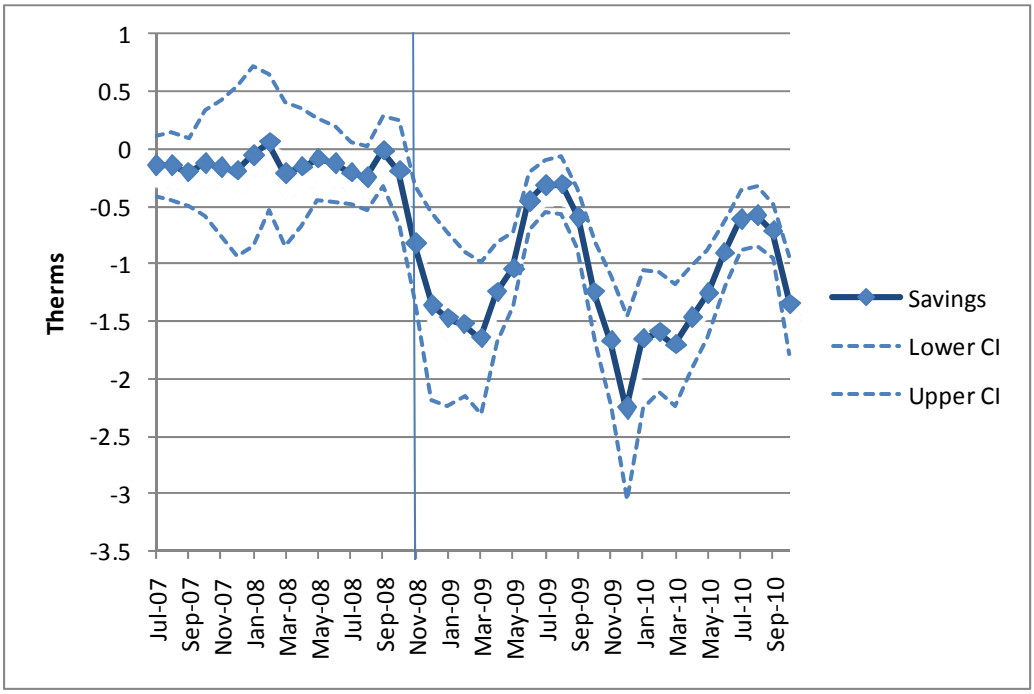

Figure 2. Average Household Monthly Gas Differences, Control vs Treatment

Full Program Annual Savings

Evaluation Results indicate a positive and increasing electric and gas savings for households which participated in the Home Energy Reports Program. We report typical year, average savings for three different timeframes.

- The first 12 months of the program, November, 2008 – October, 2009,
- All 20 months the program has been in existence, November, 2008 – June, 2010, and
- The last 12 months of the program, July, 2009 – June, 2010.

For both electric and gas the average savings increase as the timeframe includes more recent data. Figure 3 provides a visual representation of the electric and gas savings for the three different timeframes.

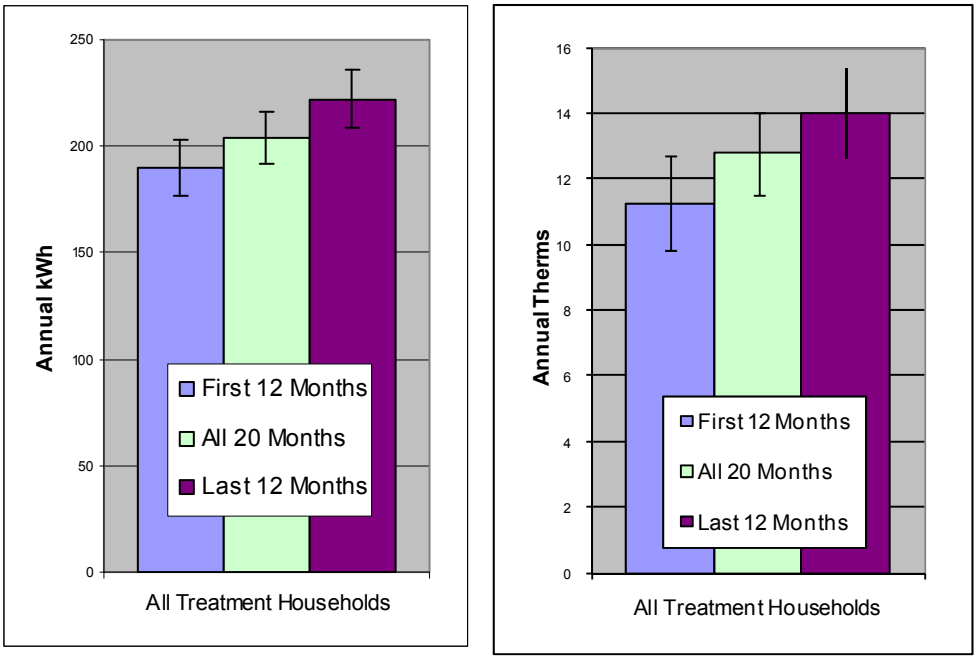

Figure 3. Full Program Electric and Gas Average Annual Savings, Three Timeframes

Table 1 shows the first year results and their associated 95 percent confidence intervals in tabular form. First year savings are estimated at 189.8 kWh and 11.3 therms per household for household receiving the reports. The table also reports average savings in percentage terms with respect to pre-report consumption and total savings for the 31,618 household for whom we can estimate savings.

Table 1. First Year Average Savings (November, 2008 – October, 2009)

Consumption	kWh/Therms	+/-*	Percent	+/-*	MW/ 1000 Therms	+/-*
Electric (kWh)	189.8	13.5	1.71%	0.12%	6,001.7	425.5
Gas (Therms)	11.3	1.4	1.17%	0.15%	356.1	44.9

*95 percent confidence level

Table 2 shows that the average annual savings over the 20 months of post-report data available average savings are estimated at 204.2 kWh and 12.8 therms.

Table 2. All Month Average Savings (November, 2008 – June, 2010)

Consumption	kWh/Therms	+/-*	Percent	+/-*	MW/ 1000 Therms	+/-*
Electric (kWh)	204.2	12.2	1.84%	0.11%	6,455.6	385.4
Gas (Therms)	12.8	1.3	1.33%	0.13%	404.2	40.0

*95 percent confidence level

Finally, Table provides the average annuals savings for the most recent 12 months for which data are available. Averages savings are estimated at 222.1 kWh and 14.0 therms.

Table 3. Last Year Average Savings (July, 2009 – June, 2010)

Consumption	kWh/Therms	+/-*	Percent	+/-*	MW/ 1000 Therms	+/-*
Electric (kWh)	222.1	13.6	2.00%	0.12%	7,021.5	430.4
Gas (Therms)	14.0	1.4	1.46%	0.14%	443.1	43.9

*95 percent confidence level

The results provided in these tables are model-based results that have been weather normalized. They reflect expected annual savings in typical weather year for the average household in the control and treatment samples.

Program Annual Savings, Monthly vs Quarterly Mailings

The PSE HER program tested two different mailing schedules for the Home Energy Reports. A subset of 25 percent of the treatment group received a report every three months, while the remainder received reports on a monthly basis[3]. Figure 4 provides a comparison of monthly and quarterly electric and gas savings for the three different timeframes. Both bar graphs show that quarterly reports generated lower savings than the monthly reports. The difference is statistically significant for all timeframes for electric savings at 95 percent confidence. For gas, the differences in the later time frames are significant at the 90 percent confidence level.

[3] The average annual savings reported above represent the overall savings for the program given this mix of monthly and quarterly reports.

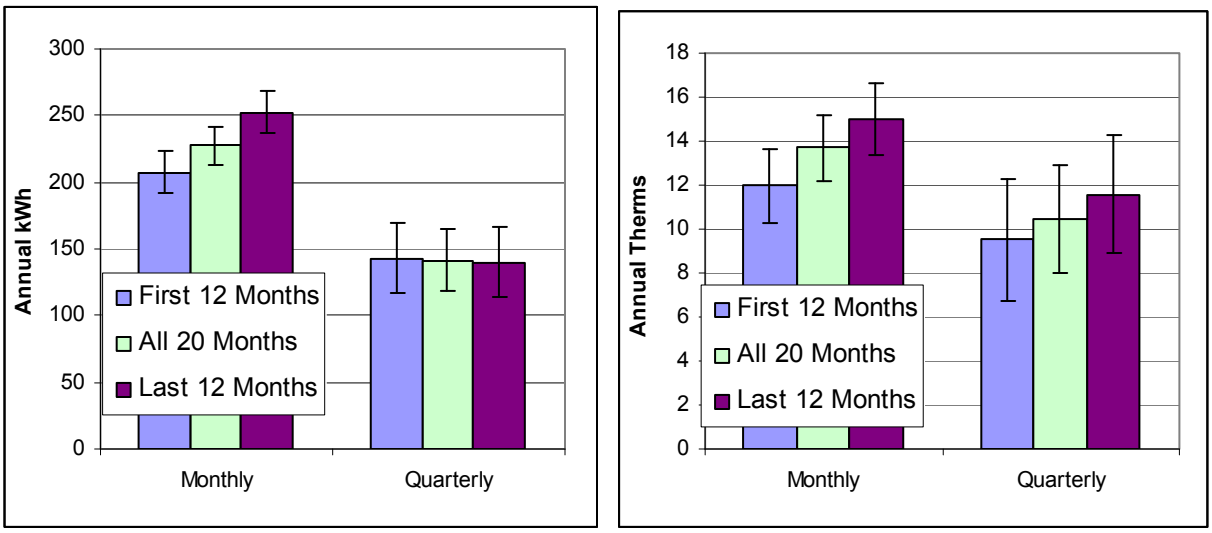

Figure 4. Monthly vs Quarterly Electric and Gas Average Annual Savings, Three Timeframes

There's an apparent difference between electric and gas savings for households receiving the quarterly reports. Gas savings were lower for household receiving quarterly reports but they increased through the timeframes in a manner similar to the monthly reports. To the contrary, electric savings for households receiving quarterly reports was effectively flat through the twenty months. Without survey data from program participants it is not possible to know for sure what is driving this difference. Gas savings are primarily related to reductions in heating consumption. It's possible that participants are lowering their thermostat set points and that these changes are more likely to be retained over the three month period between reports. To the extent that electric savings are based on behavioral changes like turning lights and other plug loads off, it's possible that such behaviors are not retained as effectively over the three month period between reports. Table 4, Table 5, and Table 6 provide the household annual savings for monthly reports versus quarterly reports in tabular form.

Table 4. First Year Average Savings (November, 2008 – October, 2009)

Consumption		kWh/Therms	+/-*	Percent	+/-*	MW/ 1000 Therms	+/-*
Electric (kWh)	Monthly	207.7	15.7	1.87%	0.14%	6,566.7	497.9
	Quarterly	143.2	26.0	1.28%	0.23%	4,527.0	822.5
Gas (Therms)	Monthly	12.0	1.7	1.24%	0.17%	378.6	52.4
	Quarterly	9.5	2.7	0.99%	0.29%	300.4	86.9

*95 percent confidence level

Table 5. All Month Average Savings (November, 2008 – June, 2010)

Consumption		kWh/Therms	+/-*	Percent	+/-*	MW/ 1000 Therms	+/-*
Electric (kWh)	Monthly	227.6	14.3	2.05%	0.13%	7,196.3	450.6
	Quarterly	141.6	23.6	1.27%	0.21%	4,478.4	745.6
Gas (Therms)	Monthly	13.7	1.5	1.42%	0.15%	433.1	46.6
	Quarterly	10.5	2.5	1.09%	0.26%	331.7	77.7

*95 percent confidence level

Table 6. Last Year Average Savings (July, 2009 – June, 2010)

Consumption		kWh/Therms	+/-*	Percent	+/-*	MW/ 1000 Therms	+/-*
Electric (kWh)	Monthly	252.5	15.9	2.28%	0.14%	7,984.0	503.4
	Quarterly	139.8	26.3	1.25%	0.24%	4,420.2	831.6
Gas (Therms)	Monthly	15.0	1.6	1.56%	0.17%	473.8	51.2
	Quarterly	11.6	2.7	1.21%	0.28%	366.3	85.7

*95 percent confidence level

Potential for Double Counting

Preliminary examination of tracking data from other PSE Energy Efficiency programs offered evidence that the Home Energy Reports have increased gas rebate program participation among treatment group households. We examined PSE Energy Efficiency programs tracking data from November 2008 to the present and identified program participants from both the treatment and control group. Comparing the participation levels between the treatment and control groups, gas rebate program installations increased for the treatment group. The gas savings due to increased program participation represent approximately ten percent of the overall HER program gas savings. If these savings were claimed by both the HER program and the rebate programs, this would amount to double counting for that portion of the HER program gas savings.

Conclusions

This paper summarizes the evaluation of the Puget Sound Energy (PSE) Home Energy Reports (HER) pilot program. The results of the evaluation help us better understand the energy savings potential of residential behavior-based conservation programs,

The evaluation confirmed savings of between one and two percent depending for the two fuels and the different 12 month periods. Consistent results were calculated using different methodological approaches. The results reported here are weather normalized savings estimates from pooled, fixed effects models.

The evaluation also confirmed that monthly reports generate more savings than the quarterly reports. The difference for gas savings is less dramatic in both magnitude and trend. The difference for electric savings is larger than for gas for the first twelve months and the difference almost doubles for the last twelve months. This indicates that more frequent mailings are particularly important when seeking electric savings.

The evaluation did indentify the potential for double counting of gas savings. The HER program treatment group increased their participation in gas rebate programs relative to the control group. This increased participation amounted to savings equaling approximately 10 percent of total HER program gas savings.

References

Navigant Consulting. Impact Evaluation of OPOWER SMUD Pilot Study. 2009. Prepared for OPOWER (with subsequent versions now available).